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On the Nervous System of Four British Columbian Barnacles (One New Species)

By I. E. Cornwall
Victoria, B.C.

(*Received for publication February 6, 1935*)

ABSTRACT

In *Lepas* six pairs of ganglia are distinct and separate; in *Balanus* two masses of fused ganglia occur; while in *Mitella* an intermediate condition exists. *Balanus* (*Balanus*) *altissimus* n. sp. differs from *B. nubilis* in the interconnections of the nerves, and in details of labrum, maxilla and sixth cirrus.

Considerable study has been given to the morphology and taxonomy of barnacles, and it is an interesting fact that Darwin's "Monograph of the Cirripedia", the two parts published in 1851 and 1854, still constitutes one of the standard works in this field. However, there are many opportunities for advancing existing knowledge of this interesting group and it is hoped that in time, life-history and ecological studies may contribute much additional information.

In the present investigation, the nervous systems of several species of various genera have been studied but only four species are dealt with in the present paper, namely, *Lepas hilli*, *Mitella polymerus*, *Balanus nubilis*, all common species on the coast of British Columbia, and *B. altissimus* n. sp. The first is abundant, usually occurring in large aggregations on floating objects. The second is universally distributed along the outer coast of British Columbia on floating or fixed objects. The third is the largest barnacle occurring on the coast. It is found in large groups at from ten to thirty fathoms (20 to 60 m.) but only in places where there is a strong tidal current. What has been previously considered a shore variety of this species and now described as a new species *Balanus* (*Balanus*) *altissimus*, occurs in the lower part of the littoral zone. It is somewhat smaller but in general appearance much resembles the deep water form.

Difficulties were encountered at first in the dissection and differentiation of the nervous system. The writer is indebted to Dr. C. H. O'Donoghue, Dr. W. K. Fisher and others for much useful information. The method finally adopted as the simplest and most successful consisted of placing a fresh specimen,

from which all calcareous matter had been removed, in a ten per cent. solution of nitric acid. The time of treatment varies considerably. Two or three days are required for large specimens whereas a considerably shorter period suffices for small specimens. The action of the acid is retarded in the dark. As a result of the acid treatment, the tissues are generally softened but the nervous material is last affected. Dissections are made in the interval between the softening of the muscles and of the nerves.

Another method may be used with specimens that have been in alcohol for some time. In these the nerves are soft and easily disintegrate. A small portion of the system is uncovered and a drawing made of it. Then a little more is uncovered and the drawing extended. This procedure is carried on till the dissection and drawing are completed. Dissection may readily be commenced at the supra-oesophageal ganglia which are located close to the oesophagus at the base of the labrum. From these ganglia the nerves may be traced near the ventral surface of the prosoma, and backward over the oesophageal ring to the infra-oesophageal ganglia.

The results of this study of the nervous system have shown: (*a*) that there are constant differences between species and that these differences are independent of those minor variations which occur among the individuals of a species; (*b*) that there is a natural series in the nervous systems of the barnacles studied which is characterized by a gradation in degree of fusion of the ganglia.

The present paper deals only with some of the major features.

Lepas hilli

The main part of the nervous system of *Lepas hilli* is shown in figure 1. Six pairs of ganglia and the commissures connecting them are illustrated but not the nerves connecting with the dorsal side of the ganglion or the fine nerves connecting with the mouth parts and the labrum. The arrangement in *Lepas* has something of the same ladder-like appearance as that of some of the Branchiopoda, but on closer examination great differences are evident. For example, in *Lepas* there is only one cross commissure forming each step of the ladder, not two as in Branchiopoda. The connectives of *Lepas* between each pair of ganglia are of nearly equal length, except those between the fourth and fifth, which are about half the length of the others. A nerve runs from each ganglion to a cirrus where it passes through the peduncle, and then divides into two, one part going to each ramus. That some concentration of the nervous system in this species may have taken place may be indicated by the fact that the nerves for the fifth and sixth cirri and the penis are all connected to the same pair of ganglia.

Mitella polymerus

In this species there are six pairs of ganglia; five infra-oesophageal and one supra-oesophageal as shown in figure 2. There is more concentration in this system than in that of *Lepas*. The first pair of infra-oesophageal ganglia are fused and appear as a single large ganglion. The connectives between it and the next pair are very short. The second, third, and fourth are paired as in *Lepas*,

but the fifth pair are fused and the connectives between the fourth and fifth pair of ganglia are not discernible.

Darwin (1851, p. 307, pl. VII.) described this species in detail, including the nervous system which he states to possess four pairs of thoracic ganglia. It is evident that he considered the fourth and fifth pairs as one. In view of the condition existing in *Lepas*, there is no question but that *Mitella* should be considered as possessing five pairs of infra-oesophageal ganglia.

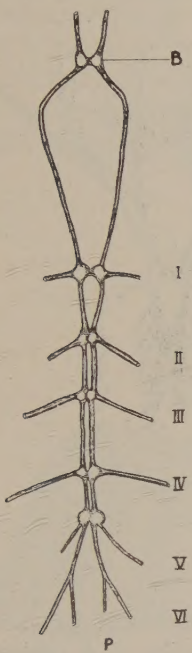

FIGURE 1. Ventral view of the nervous system of *Lepas hilli*. B,—supra-oesophageal ganglia; I to VI,—nerves to cirri; P,—nerve to penis.

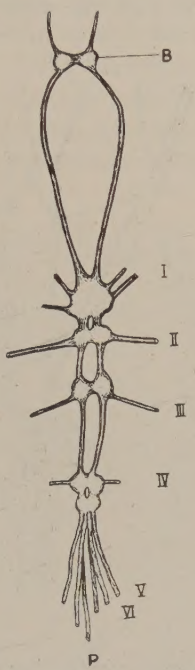

FIGURE 2. Ventral view of the nervous system of *Mitella polymerus*. B,—supra-oesophageal ganglia; I to VI,—nerves to cirri; P,—nerve to penis.

Balanus nubili

The nervous system of *Balanus nubilis* is shown in figure 3a. The large infra-oesophageal ganglion occurs between the first and second cirri. It clearly shows traces of having been formed of several pairs of ganglia which have been coalesced as indicated by a line of small holes on the median line. The nerves supplying the posterior cirri are parallel and close together. The members of a pair branch off in succession to each pair of cirri until there are only two pairs left. These run together for some distance, one pair going to the sixth pair of cirri and the remaining one to the penis. The junction of these nerves forms the posterior margin of the infra-oesophageal ganglion. The anterior margin is formed by the junction of the nerves which form the oesophageal ring, and of the great splanchnic nerves. The nerves for the first and second cirri branch off

from the sides of the ganglion. There are two large nerves connected to the dorsal part of this ganglion.

From each side of the oesophageal ring a branch is given off which passes direct to the splanchnic nerve, figure 3a, S. Just anterior to the points of junction, the splanchnic nerve forks. The place of origin and the length of the branch from the oesophageal ring, as well as the position of its point of junction with the splanchnic nerve, varies in different individuals but connection is always made with the main splanchnic nerve, rather than with the branches.

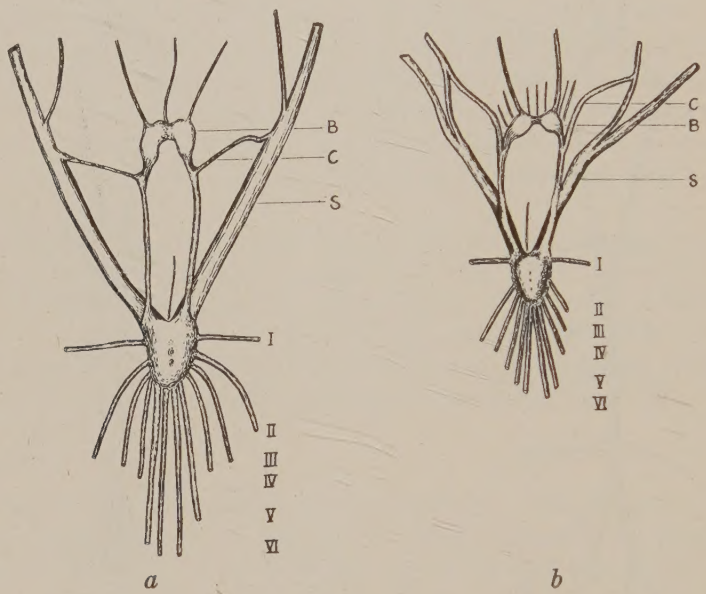

FIGURE 3. Ventral view of the nervous system of (*a*) *Balanus nubilis*; (*b*) *B.* (*Balanus*) *altissimus*. B,—supra-oesophageal ganglia; S,—splanchnic nerve; I to VI—nerves to cirri;, C,—connective.

Balanus (Balanus) altissimus n. sp. (figure 4a)

In the littoral zone there occurs a barnacle which has heretofore been considered a form of *Balanus nubilis* (Cornwall 1925). Examination of the nervous system discloses the existence of a definite and constant difference in the arrangement of the nerves from that occurring in the typical *B. nubilis*. This is shown in figure 3b. It will be seen that the branch from the oesophageal ring passes not to the main splanchnic nerve but to its inner branch. The length of the oesophageal branch varies as does the point of union but the junction is always with the branch and not with the main splanchnic.

The discovery of this fact led to a critical examination of the littoral form, and it was found that there existed many other constant differences from *Balanus nubilis* and any other known species. Therefore the littoral barnacle is described as a new species.

In both forms the supra-oesophageal ganglia are small when compared with

the infra-oesophageal ganglion. The supra-oesophageal ganglia occur at the base of the labrum, and are connected by a short, thick commissure. From the middle of this commissure a small optic nerve branches off on the anterior side and passes along near the ventral surface of the prosoma. A small ganglion occurs at the point where the nerve divides to supply each eye.

Description. Size of type: greatest diameter, 75 mm.; height, 41 mm.; orifice, 28 mm. by 31 mm.; shell conical, carina steepest part. Carinolaterals narrow. Sculpture rough and surface worn, exposing upper part of pores. Sheath deep, being about half the height of the shell. Basis solid with thickening near periphery but no trace of pores. No specimen has been found where room has been gained by deepening the basis as is common in *Balanus nubilis*. Inside of wall ribbed for short distance from basis, these ribs corresponding with the

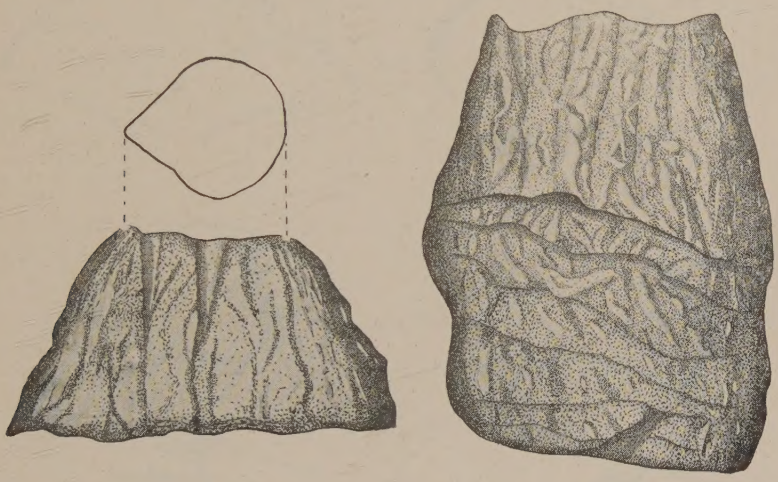

FIGURE 4. Shells—(*a*) *Balanus altissimus*; (*b*) *B. nubilis*, showing deepened base.

walls between the pores in the walls. Parietal tubes large near the basis but small toward summit of shell. No cross septa as in the pores of *Balanus nubilis* (Cornwall 1925).

Labrum (figure 5a) deeply notched but not as widely open as in *Balanus nubilis* (figure 5e). Row of fine hairs near margin of notch but no teeth. Margin of labrum straight on each side of notch, thus differing from that of *B. nubilis*.

Mandible (figure 5b) with four teeth on the cutting edge; lower margin strongly convex, thus differing from that of *B. nubilis* which is straight or slightly concave (figure 5f).

Maxilla (figure 5c) about same shape as in *B. nubilis* (figure 5g); but upper pair of spines longer and lower spines shorter; lower margin slightly more prominent.

First cirrus similar to that of *B. nubilis*, but median segment of sixth cirrus with only four spines (figure 5d) as contrasted with six in *B. nubilis* (figure 5h).

Scutum resembles that of *B. nubilis* but is smaller.

Tergum much as in *B. nubilis* but crests for attachment of depressor muscles more numerous, and extending farther toward apex; these crests deep and regular whereas in *B. nubilis* they are shallow and irregular.

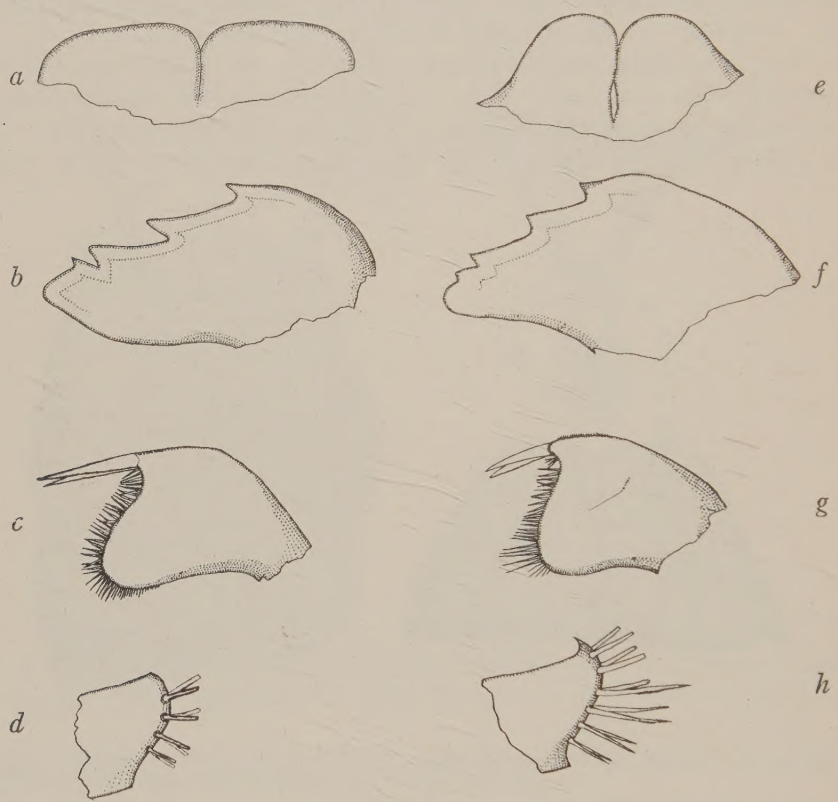

FIGURE 5. Mouth parts of *Balanus altissimus*—(*a*) labrum; (*b*) mandible; (*c*) maxilla; (*d*) portion of median segment of sixth cirrus showing four pairs of spines. Mouth parts of *B. nubilis*—(*e*) labrum; (*f*) mandible; (*g*) maxilla; (*h*) portion of median segment of sixth cirrus showing six pairs of spines.

In the nervous system, nerve from oesophageal ring joins branch of splanchnic nerve (figure 3b); in *B. nubilis* nerve from oesophageal ring joins main splanchnic nerve before latter gives off branch (figure 3a).

In summary, *B. altissimus* differs from *B. nubilis*, its nearest relative, in the following characters: (1) the structure of the shell; (2) the sculpture of the interior of the tergum; (3) the mandible; (4) the maxilla; (5) the labrum; (6) the number of spines on the median segment of the sixth cirrus; and (7) the arrangement of the nerves from the oesophageal collar.

Distribution. Collected from many places on the southern coast of Vancouver island.

Type. The type specimen has been deposited with the Pacific Biological Station, Nanaimo, B.C.

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DARWIN, CHARLES. A monograph of the Cirripedia. London. 1851.

Food of *Clupea pallasii* in Southern British Columbia Waters

By G. H. Wailes
Vancouver, B.C.

(*Received for publication March 4, 1935*)

ABSTRACT

The food of the Pacific herring *Clupea pallasii* consists during the larval stage principally of ova of various kinds with circular diatoms. No food was found in fish less than 9 mm. in length. Postlarvae and fry take the greatest variety of food, Copepoda and Cirripedia larvae being the most important items. Apparently the most readily available of suitable foods is taken. Adults confine themselves to a crustacean diet (except herring ova occasionally), Copepoda and Euphausiacea comprising the bulk of the food, *Calanus* predominating in the spring and *Euphausia* during the remainder of the year. Purse seined herring rarely contained any food. Copepoda are on the whole the most important food of the Pacific herring.

Herring at all stages in their life history occupy an important intermediate position in the marine food chain (Lebour 1924, Hardy 1924, Wailes 1929) which transforms plankton organisms into products utilizable by man. Ford (1929) has pointed out the desirability of and difficulties in raising young herring from the egg to stages beyond metamorphosis: it appears reasonable that knowledge of the proper food is essential to so doing. As there is no evidence of a close relationship between the number of eggs deposited at spawning and the number of mature fish produced, it must be assumed that the number of young fish to survive is controlled by some limiting factor. The most probable limiting factor appears to be the food supply of the very early stages. For these reasons the food of herring—particularly of the young fish—is of especial interest.

MATERIALS AND METHODS

The food of British Columbia herring was investigated by examining the contents of the alimentary tracts of herring in 67 samples. The number of fish examined in each sample varied considerably ranging from 1 to 25. However, in most cases 10 fish from each sample were considered if they were available. Observations in addition to those made on the samples have been used in drawing some of the conclusions.

Seven samples were examined from 1931, 44 from 1932, 8 from 1933, and 8 from 1934. As fish in a single length group may have been collected in different samples it is impossible to assign definite dates to each length group. However,

approximate dates can be assigned to the various size groups of young fish on the following basis. In southern British Columbia spawning of herring usually takes place in March, the young hatch in two to three weeks, by the beginning of May the postlarvae are about 2 cm. long, and by the first of July the fry have reached lengths in the neighbourhood of 5 cm.

The collections represent a number of localities: Nanoose bay provided 27 samples; Departure bay, 23; Pender harbour, 5; Fulford harbour and point Grey, each 3; Saanich inlet, 2; Telegraph harbour, Porlier pass, Esperanza inlet, and Sydney inlet, each 1. Nanoose bay and Departure bay supplied all of the larval and postlarval stages. All of the localities mentioned in this paper are in the vicinity of the strait of Georgia except Esperanza and Sydney inlets which are on the west coast of Vancouver island.

The samples from point Grey and Pender harbour were taken by gill nets in the summer months but all others represent most of the few fish containing food, sampled in the winter purse seine fishery during studies extending over four years. One sample of adult fish was raked at Departure bay. Larvae were taken by trawls, postlarvae by dip nets and beach seines, and fry by beach seines and dynamite.

Fifty-five of the samples consisted of fish of the year, namely, larvae, postlarvae, and fry; 1 was of second year fish; and the remaining 11 samples consisted of adults in their third year or older.

To examine the food, the contents of the alimentary tracts of the fish were dissected out before or after preservation and the relative volume of organisms of each species was estimated by inspection through a microscope or low power binocular, taking into account the number of individuals and the average bulk of these.

The fish were divided into length groups having a 2 mm. interval up to 17 mm. length and a 5 mm. interval from 25 mm. to 120 mm. All adults were considered together. In larvae and immatures the over-all length was used, in adults the length to the end of the silvery area on the caudal peduncle after the scales were removed. For each locality and year the average proportion of each food organism was calculated; similarly a total summary for all years and localities was drawn up. Fish having empty digestive tracts were omitted from all calculations.

Results obtained in this way may have errors from several sources. There is the initial difficulty of making an estimate of the volume of an object from its projection in two dimensions. Small, soft forms such as unshelled protozoa which are readily digested in the anterior part of the gut are likely to be missed more often than forms which are large or have readily identifiable hard parts such as tintinnids, diatoms, and copepods. It is found that preservatives alter some protozoa beyond recognition. In the case of some of the larger fish with well developed stomachs, digestion was evidently rapid, since the food organisms were so badly macerated that copepods for whose identification the fifth leg was necessary could not be specifically determined. In all cases identifications were made as fully as possible when the stomach contents were examined, even

although frequently it was found desirable to consider a number of species or groups together in making subsequent tabulations.

Certain difficulties arise in the summarization of data of this kind due to the frequently observed similarity in food from specimens in the same samples and the fact that all samples are not of the same size. In spite of this the averages presented have been obtained by averaging the percentage stomach contents of individual fish in a size group. In so doing certain sources of error have been avoided and it is felt that in spite of the difficulties there has been no distortion of the results affecting the important conclusions.

The author wishes to express his thanks to Dr. J. L. Hart and Mr. A. L. Tester for suggestions and material. The former is responsible for interpreting much of the data and for the data on the absorption of the yolk sac; the latter assisted materially in consultation and by supplying the information in regard to the relationship of season and method of capture to the amount of food found in adult herring.

RESULTS AND DISCUSSION

The results of the investigation are summarized in table I and in figure 1. In the former is a list of some ninety kinds of food found in the stomachs of herring in the course of the investigation, along with the relative importance at various stages of development of each kind of food. The figure has been drawn from the data obtained in the total summary. In it the group "miscellaneous" (misc.) includes, besides unidentifiable material, Flagellata, Ostracoda, Amphipoda, Tunicata, and Algae. Of these, Amphipoda and Tunicata, with maximum percentages in single length groups of 3.6 and 0.9, respectively, are the more important of the definable classes. By far the greatest proportion of the miscellaneous group is comprised of unidentifiable material.

Absorption of Yolk Sac and First Feeding Stages

The young herring average approximately 7.5 mm. in total length when they hatch. However, although the mouth is open at hatching time, as recorded by Fraser (1915) and Lebour (1921), the young fish evidently do not start to feed immediately. The smallest fish found to contain food was 9 mm. in length although it is possible that food is taken at earlier stages. As reported by other authors food is taken before the yolk sac is absorbed. In two samples totalling 19 fish between 7.0 mm. and 8.0 mm. none contained food. In a sample of 23 between 6.0 mm. and 10.0 mm., 6 contained food. In a sample of 12 between 9.0 mm. and 10.0 mm., 3 contained food. In a sample of 10 between 9.0 mm. and 12,0 mm., 7 contained food. In many samples of somewhat larger fish no food was found. This may be caused as suggested by Hardy (1924) by the evacuation of the intestinal tract by the postlarvae on the approach of danger.

As reported by other authors, notably Lebour (1918), the length at which the yolk sac disappears is subject to a great deal of variation in fish from the same area. In the specimens examined in the present study, the shortest fish having no yolk sac was 6.0 mm. long and the longest fish observed with traces of the yolk was 11.0 mm. in length. There is some evidence for the belief that

differences in spawning time may influence the average differences (Hardy 1924) between localities in length at the time when the yolk sac is absorbed. Of the young herring presumably resulting from a spawning at Nanoose bay on March 2,

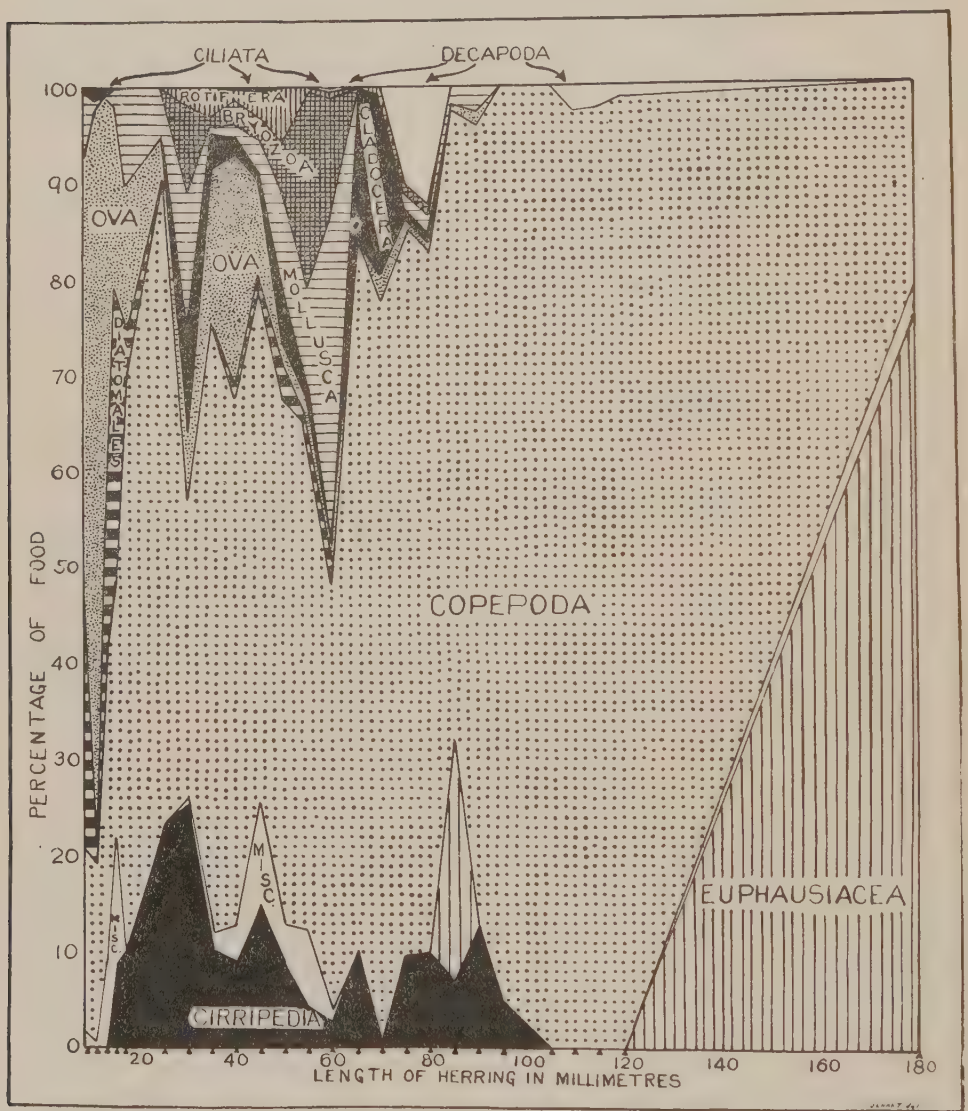

FIGURE 1. Relative importance of the major groups of food organisms of herring at all stages of development. The positions representing the various length groups are indicated by the points immediately below the base line and the percentage of food of each kind for the length is shown by the vertical distance in the various areas above the point.

1932, practically all had yolk sacs when newly hatched on March 17 and had the following length distribution (to 0.5 mm.): 7.0 mm., 2; 7.5 mm., 5; 8.0 mm., 2; 8.5 mm., 1. On March 24 the length distribution of those still having the yolk

TABLE I.—Organisms found in the digestive tracts of herring in 67 samples, with the approximate size of the organisms and the relative importance in the food of herring of different sizes. x indicates the presence of an organism, xx indicates that it is an important item in the diet and xxx that it is of dominant importance.

Approximate size		Relative importance in food at lengths (mm.)					
		9 to 12	13 to 27	28 to 43	44 to 72	73 to 120	more than 121
(μ)							
	Flagellata						
30	*Ebria tripartita*	–	x	–	–	–	–
150	*Peridinium depressum*	–	–	x	x	–	–
70	" *conicum*	–	–	–	x	–	–
65	" *grani*	–	–	x	–	–	–
85	" *leonis*	–	–	x	–	–	–
40	" spore	x	–	–	–	–	–
	Ciliata						
100	*Tintinnopsis karajacensis*	x	x	–	–	–	–
150	" *cylindrica*	–	–	x	–	–	–
65	" *parvula*	x	x	–	–	–	–
35	*Stenosemella pacifica*	x	–	–	–	–	–
40	" *nivalis*	x	–	–	–	–	–
240 x 90	*Favella franciscana*	–	–	x	x	–	–
200 x 100	" *serrata*	–	–	x	–	–	–
200 x 25	*Helicostomella subulata*	–	–	x	–	–	–
100 x 75	*Ptychocylis urnula*	x	–	–	–	–	–
	Ova						
80	*Trochiscia clevei*	xxx	xx	–	–	–	–
200	" *moebiusi*	–	x	–	–	–	–
	Ova under 70 μ dia.	x	xx	xx	x	–	–
	70 to 100 μ dia.	xx	x	x	x	x	–
	100 to 200 μ dia.	xx	x	x	x	x	–
	200 to 400 μ dia.	x	–	xx	x	x	–
	Rotifera						
500 x 200	*Synchaeta baltica*	–	–	x	x	–	–
220 x 100	*Notholca* sp. nov.	–	–	x	–	–	–
	Bryozoa						
525	*Membranipora* spp. larvae	–	–	x	xx	x	–
	Echinodermata						
600	*Asteroidea gastrula*	–	–	x	–	–	–
	Mollusca						
100–400	Bivalve larvae (*Ostrea lurida* and *Mytilus edulis*, etc.)	x	xx	x	xx	x	–
400	Gastropod larvae	x	xx	–	x	–	–
100–200	Pteropods and larvae	x	x	x	x	–	–
10	Gastropod ova spp.	–	–	–	x	–	–

TABLE I (*continued*)

Approximate size (mm.)		Relative importance in food at lengths (mm.)					
		9 to 12	13 to 27	28 to 43	44 to 72	73 to 120	more than 121
	Cladocera						
1.0	*Evadne nordmanni*	–	–	x	x	–	–
1.0	" *tergestina*	–	–	–	x	–	–
0.5	*Podon polyphemoides*	–	–	x	x	x	–
0.8	" sp.	–	–	x	–	x	–
0.4	Ostracoda sp.	–	–	x	x	–	–
	Copepoda						
	Calanoida						
4–6	*Calanus tonsus* ♀	–	x	x	x	xxx	xx
4–8	*Eucalanus elongatus*	–	–	–	x	–	–
1	*Paracalanus parvus*	–	–	–	x	–	–
1	*Pseudocalanus elongatus*	–	x	x	x	x	x
0.7	*Microcalanus pusillus*	–	–	x	xx	–	–
1.6	*Centropages mçmurrichi*	–	–	x	x	x	x
3	*Metridia lucens*	–	–	x	–	–	–
4	" *longa*	–	–	x	–	–	x
1.2	*Acartia clausi*	–	–	x	x	–	–
1.1	" *longiremis*	–	xx	x	x	–	–
1.8	*Tortanus discaudatus*	–	–	–	–	x	x
	Harpacticoida						
0.7	*Microsetella rosea*	–	–	x	x	–	–
1.3	*Diosaccus spinatus*	–	xx	–	x	x	–
0.7	*Amphiascus phyllopus*	–	xx	x	x	–	–
	spp.	–	x	–	–	–	–
	Cyclopoida						
0.8	*Corycaeus affinis*	–	–	x	x	–	–
0.7	*Oncaea borealis*	–	x	x	–	–	–
0.5	" *subtilis*	–	–	–	x	–	–
1.7	*Lepeophtheirus* sp.			x			
0.7	*Oithona helgolandica*	–	–	–	x	x	–
2	*Caligus* sp. (larva)	–	–	–	x	–	–
1–3	Juveniles spp.	xx	–	xx	x	xx	–
	Nauplii spp. early stages	xxx	–	x	x	x	–
	" spp. later stages	–	xx	xx	x	xx	–
	Cirripedia						
1.2	*Balanus* cypris	–	–	x	x	x	–
0.3	" nauplii	–	xx	xx	xx	x	–

TABLE I (*continued*)

Approximate size		Relative importance in food at lengths (mm.)					
		9 to 12	13 to 27	28 to 43	44 to 72	73 to 120	more than 121
(mm.)							
	Amphipoda						
1	*Cyphocaris challengeri*	–	–	–	–	–	x
2	*Hyperiidae* sp. juv	–	–	x	x	–	–
3	*Caprella* sp	–	–	–	–	x	–
	Euphausiacea						
20	*Euphausia pacifica*	–	–	–	–	xx	xxx
	Decapoda						
2–6	Crab zoea spp	–	–	x	x	xx	–
6	Shrimp larvae spp	–	–	x	x	x	x
	Tunicata						
3	*Appendicularia* sp	–	–	x	x	–	–
(μ)	Diatomales						
200	*Coscinodiscus centralis*	x	x	x	x	–	–
350	" *wailesi*	–	–	–	x	x	–
120	" *radiatus*	x	x	–	x	–	–
125	" *stellaris*	–	–	–	x	–	–
105	" *excentricus*	x	x	x	x	–	–
100	" *curvatulus*	–	–	–	x	–	–
80	*Stephanopyxis palmeriana*	–	–	–	x	–	–
20–35	*Thalassiosira decipiens*	x	xx	–	–	–	–
20–40	" *nordenskioeldi*	–	x	–	–	–	–
40	*Ditylum brightwelli*	–	–	–	x	–	–
40	*Cerataulina bergoni*	–	–	–	x	–	–
100	*Biddulphia arctica*	x	x	x	x	–	–
150	*Isthmia nervosa*	–	–	–	x	–	–
25	*Navicula forcipata*	xx	x	x	x	–	–
20 x 120	*Pleurosigma fasciola*	–	–	–	x	–	–
25 x 65	*Amphora cymbifera*	–	–	–	x	–	–
	Miscellaneous						
100	Conifer pollen grains	–	x	–	–	–	–
150	Gastrula	–	x	x	–	–	–
	Digested material	x	–	x	xx	–	–
	Cladophora sp	–	–	x	–	–	–
	Unicellular	x	x	x	x	–	–

sac was: 8.0 mm., 4; 8.5 mm., 4; 9.0 mm., 2; and that of those with the yolk sac absorbed was: 8.0 mm., 2; 8.5 mm., 0; 9.0 mm., 3; 9.5 mm., 2; 10.0 mm., 2; 10.5 mm., 1. In the second sample about seventy per cent had the yolk sac absorbed. Young herring with yolk sac present presumably resulting from a spawning at Horswell point, 12 miles from Nanoose bay, on March 23, 1932, showed the following length distribution on April 12: 6.0 mm., 2; 6.5 mm., 2; 7.0 mm., 5; 7.5 mm., 2; 8.0 mm., 1; and those with the yolk sac absent showed a length distribution as follows: 6.0 mm., 1; 6.5 mm., 4; 7.0 mm., 4; 7.5 mm., 1; 8.0 mm., 3; 8.5 mm., 1. Water temperatures at Departure bay representative of the sixteen-day periods following March 2 and March 23 were, respectively, 6.8° C. and 7.6° C. It appears possible that water temperature by affecting rate of development is related to the length at which the yolk sac is absorbed.

Ova of various kinds were an extremely important item of food during the early feeding stages; indeed, the large numbers of *Trochiscia clevei* in the food in many cases was surprising in view of its relatively large size and armature of spines. Diatoms were relatively important for a short time. Moreover, there appeared to be a selection on the part of the young fish of diatoms having more or less regular shape. For example, species of *Coscinodiscus* were found commonly in the stomachs, whereas filamentous forms such as *Thalassiosira* were found sparingly and spinous forms such as *Chaetoceros* not at all although both are regularly present in the plankton. Mollusca also were important up to a length of 60 mm. but in contrast to the results reported by Lebour (1934, etc.), these were principally bivalves. Even during the earliest feeding stages, small copepod nauplii form a very considerable part of the food. Ciliata comprised an appreciable part of the food at this stage and it is possible that owing to the method of examination they and other unicellular plants and animals are inadequately represented in the results. On the whole, ova, Copepoda, and Diatomales in the order named were the most important food groups during the earliest feeding stages. These relationships are shown in detail in the figure. There is no sharp break in the feeding habits, and animal and plant materials may be found in the same stomachs. For example, a specimen 9.0 mm. in length from Nanoose bay, April 5, 1932, contained *Peridinium* spore $40\mu-1$, *Coscinodiscus radiatus* $97\mu-1$, ova $100\mu-2$, copepod nauplius-1.

Postlarvae and fry

At intermediate stages of development (20$-$100 mm.) a considerable variety of foods is taken. The order of importance of these was as follows: Copepoda, Cirripedia, Mollusca, ova, Bryozoa, Cladocera, Rotifera, Decapoda, and Euphausiacea. An examination of the summaries of the food found in individual samples showed that fish of the same stage in the same locality in two successive years do not necessarily take the same food. This is also found to be the case for fish of the same stage taken in different localities in the same year. These results indicate that the young fish are taking what is most readily available rather than that different preferences are being exercised. There is no evidence in the results indicated in figure 1 for the narrowing down of the number of food organisms during postlarval life such as that recorded for Western channel and

North sea herring by Lebour (1921) and Hardy (1924), since even diatoms are taken in appreciable quantities until a length of 60 mm. is reached. On the whole, any change in the nature of the dietary would appear to be in the opposite direction and a great variety of food organisms is taken until a length of 80 or 90 mm. is reached. This observation appears to apply to individuals also for there is no evidence of specialization on one type of food by juveniles.

Adults

The food of the adults consisted entirely of Crustacea, *Euphausia pacifica* holding a dominant position and Copepoda comprising most of the rest of the food. The lack of variety in the food may be a consequence of the small number of adult fish having food in their stomachs for examination. As has been noticed by other authors (Fraser 1922, Hardy 1924), mature herring taken on the spawning grounds are occasionally gorged with herring eggs. Among the adults there is some evidence of specialization on one type of food by certain individuals. For example, in a sample of 13 gill netted herring from Pender harbour, 12 had eaten *Euphausia pacifica* to the exclusion of all other foods, while the thirteenth had eaten 100 per cent *Cyphocaris challengeri*.

The data are not sufficiently extensive to warrant a definite statement in regard to changes in food organisms with the season of the year. However, the possibility of seasonal changes in this regard is suggested by an examination of the stomach analyses of all feeding adult fish. Observations made on three groups of herring taken in April and May showed them to have eaten, respectively: 98 per cent *Calanus tonsus*, 2 per cent miscellaneous; 80 per cent *Calanus finmarchicus*, 20 per cent. *Euphausia pacifica*; 100 per cent. *Calanus tonsus*. In contrast to Fraser's (1922) findings that copepods were the principal food, stomachs of 132 fish taken at 12 different times between July 18 and January 19 contained almost entirely *Euphausia pacifica*, the only exception being that fish taken on September 15 and October 13 contained 45 and 7 per cent *Cyphocaris challengeri*, respectively.

In the course of sampling during 1932, 1933, and 1934, 13,158 mature herring from 112 samples have been examined from commercial purse seine and gill net catches representing all months but May and June. Of 11,102 fish in 95 samples from the purse seine fishery, only 6 fish (0.05 per cent) from 3 samples contained food in appreciable quantities. These fish were caught in January and November. No purse seined samples were taken from May to September inclusive. Of 2,056 fish in 17 samples from the gill net fishery, 314 fish (15 per cent) from 6 samples contained food in appreciable quantities. Gill net samples were obtained in March and the months from July to December but no food was found in the 4 samples taken in March, August, and November. These results are directly at variance with those of Jespersen (1932) who ascribes the relatively low stomach contents of gill-netted fish to the fact that they had been caught at greater depths where temperatures are low and food organisms comparatively scarce. The differences in the results may be entirely due to differences in the way in which the two types of gear are used (see Tester 1935). Food was found in large specimens taken with dip nets and rakes on

three different occasions in April and May at times when the commercial fishery is not actively pursued. These data indicate that when herring are in compact schools suitable for the activities of a successful purse seine fishery, they are not actively feeding. It appears that herring take food to some extent at most seasons of the year although the data here are too fragmentary to indicate at what season feeding is most active. The most suggestive information in this respect is that all the stomachs of the samples taken in April and May were filled but this fact may be related to the method of capture.

The most striking feature of the food of the herring, well illustrated in figure 1, is the extreme importance of copepods throughout the whole life span. At first, early nauplii were taken; as the small fish grew, juveniles and small adult copepods became increasingly important in the diet and by the time a length of 5 cm. had been reached it was possible for the young herring to ingest adult *Calanus tonsus*. This species was the chief form eaten by the larger stages.

SUMMARY

The food of the Pacific herring, *Clupea pallasii* Cuvier and Valenciennes, was studied by examining the contents of the digestive tracts of herring at all stages of development taken at a variety of localities and times.

No food is reported from fish less than 9 mm. in length although food is taken before the yolk sac is absorbed. Herring larvae resulting from different spawnings differ in the length at which the yolk sac is absorbed.

In the earliest feeding stages ova of various kinds are the most important food; diatoms of regular shapes are taken more frequently than others and small copepod nauplii are eaten.

Postlarvae and fry take the greatest variety of food organisms with copepod and cirripede larvae the most important items. Differences between localities and seasons suggest that the food most readily available is taken.

Adults eat *Euphausia* and Copepoda principally, and occasionally herring eggs. There is evidence for beliefs in individual specialization on certain types of food, and for seasonal changes in kind of food taken, *Calanus* being most important in the spring and *Euphausia* during the rest of the year. Purse seined herring seldom contain food, suggesting that fish in compact schools are not feeding.

Copepoda are on the whole the most important food of herring.

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Fish Oils

V. The Effect of Various Treatments on the Rate of Oxidation of Pilchard Oil

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ABSTRACT

Pilchard oil has a shorter inductive period and a greater rate of oxidation than other drying oils. Polymerization by heat prolongs the inductive period and diminishes the rate of oxidation whilst polymerization by ultra-violet radiation shortens the inductive period, increases the rate of oxidation and reduces the total amount of oxygen absorbed. Refining increases the susceptibility of the oil to oxidation. Treatment with dry sulphur dioxide eliminates the inductive period. Oxygen-absorption curves obtained by a manometric method are submitted to show the influence of driers, mineral pigments and anti-oxidants, on the rate of oxidation of the oil.

This paper is the second of a series concerning the drying properties of Canadian pilchard oil. For convenience of presentation, the subject of oxidation is discussed separately from the drying of the oil and the properties of films. These topics will be dealt with in the next paper of the group.

In contact with air all naturally occurring oils and fats absorb oxygen. The absorption does not begin immediately, but is preceded by an "inductive period" or interval during which there appears to be a resistance to the action of oxygen. At the end of the inductive period the absorption of oxygen begins slowly and proceeds with increasing rapidity, the rate depending upon the unsaturated character of the oil or fat. Among the first products of oxidation are peroxides. These in turn catalyze the further reaction with oxygen. Consequently, oxygen-absorption curves are of the autocatalytic type. It was formerly assumed that the inductive period represents the time necessary for the formation of peroxides but this is not the complete explanation. The studies of Moureu and Dufraisse (1926), Holm, Greenbank and Deysher (1927), Hilditch (1930), Mattill (1931), Elm (1931), Hilditch and Sleightholme (1932) and others have revealed the fact that naturally occurring oils and fats contain substances which inhibit the action of oxygen and hence are partly responsible for the inductive period. These natural "anti-oxygens" have a greater affinity for oxygen than have the oils themselves, and hence it is only after they have become oxidized that the oxygen attacks the glycerides. In support of this theory

Hilditch and Sleightholme (1932) point out that the distilled methyl esters of fatty acids of natural oils or fats oxidize much more rapidly than do the oils themselves. The writers have found this to be particularly marked with distilled methyl esters of the fatty acids of pilchard and other highly unsaturated fish oils.

In the presence of driers (metallic compounds which catalyze the oxidation and solidification of drying oils) such as the oxides or organic salts of cobalt, manganese, lead, etc., the inductive period of oils and fats is either entirely eliminated or greatly reduced. The effect on the rate of oxidation and on the properties of the oxidized product varies with different driers, but it is generally believed that they act by forming higher unstable oxides or peroxides which subsequently decompose yielding oxygen in an active form. This simple view, however, does not explain all the properties of driers. Various theories, therefore, based on intermediate compound formation (Ingle 1917), physical adsorption (Slansky 1925), etc., have been put forward, but none is completely satisfactory. It is well known that the activity of a drier depends considerably on the manner of preparation, its solubility in the oil, the method of incorporation in the oil, and the nature of the oil. Cobalt and manganese have been found by nearly all investigators to be the most efficient driers but the relative efficiencies of the other metals are not so well defined. Pigments also are known to have a marked effect on the rate of oxidation of oils. For example, the umbers, brown pigments which contain a fairly large amount of manganese, accelerate oxidation. Certain other pigments containing iron and lead have a similar, though less pronounced, influence. The so-called "inert" pigments and fillers may retard oxidation as a result of adsorption of peroxides or the drier itself on the surface of the pigment particles or by impeding the diffusion of oxygen through the film. Here again the effect of pigments varies somewhat with the nature of the oil.

Oxidation is an important primary step in the solidification of drying oils. It is thought that in the absence of a drier, peroxides are first formed which then break down to the oxide, the extra oxygen reacting with other molecules of oil. When driers are present, peroxides are not detectable; presumably therefore oxidation proceeds directly to the oxide stage. What happens to the oxides is not definitely known but at this stage volatile decomposition products are formed and the oil begins to "gel". Whether decomposition precedes polymerization and gelation or whether polymerization takes place directly between the oxides of the oil has yet to be established, but in any event oxidation of the olefinic compounds through the peroxide stage to associable compounds is necessary before polymerization can take place (Elm 1931). After gelation of the oil to a solid film, oxidation still goes on, though more slowly, and finally may cause failure of the film. The rate of oxidation is therefore an important factor both in the solidification of drying-oil films and in their durability.

Pilchard oil can be classed as a drying fish oil but as pointed out in a previous publication (Brocklesby and Denstedt 1934) it differs considerably in composition from that of the better known drying vegetable oils; consequently many of the effects noted above regarding the oxidation of drying oils are modified with respect to this oil. The effect of some of the more important treatments on the rate of the oxidation of pilchard oil will be described.

MATERIALS AND METHODS

For all experiments fresh commercial pilchard oil was used. It was first stearin-cleared at 6° C. as described in a previous communication (1934).

Oxygen absorptions were measured at 25° C. by a manometric method described in a previous communication (1931). This method does not give absolute measurement of the total oxygen absorption, but it gives reliable relative measures of the inductive period and the rate of the initial oxygen absorption. Good comparisons were obtained between this method and the gravimetric method.

BEHAVIOUR OF RAW AND REFINED OILS TOWARDS OXYGEN

In figure 1 are shown the oxygen-uptakes of raw pilchard oil, raw linseed oil (Canadian) and raw China wood oil. It will be observed that pilchard oil has a shorter inductive period than either of the other oils. This may be due in part to a lower content of anti-oxygens, but it is more likely attributable to the presence of tetra- and penta-ethylenic fatty acids which oxidize more readily than the less highly unsaturated fatty acids and even than the so-called anti-oxygens. These highly unsaturated fatty acids rapidly form peroxides in the presence of oxygen, and hence shorten the inductive period and accelerate further oxidation. The susceptibility of these fatty acids to oxidation is also shown by the effects of added anti-oxygens. In equal concentrations, hydroquinone or maleic anhydride prolong the inductive period of linseed and other less highly unsaturated oils much more than in the case of pilchard oil.

The drying times of the oils listed in figure 1 are not strictly proportional to their rates of oxygen absorption. When brushed out on glass plates and exposed to the atmosphere of the laboratory the raw China wood oil dried in 3 days, pilchard in 9 days and the linseed in 12 days. Materials that increase the oxygen absorption of pilchard and linseed oil, however, always decrease the drying time accordingly.

Holm, Greenbank and Deysher (1927) and others have shown, during refining of raw oils, that the anti-oxygens apparently are removed. Refined oils, therefore, are more susceptible to oxidation. The following experiment will illustrate this in the case of pilchard oil.

Four 100-gram samples of pilchard oil were heated on the water bath to approximately 98° C. and then treated as follows:

Sample 1,—two grams of decolourizing carbon were added and the mixture was stirred rapidly for five minutes, then cooled and filtered.

Sample 2,—two grams of Filtrol C-200 (a commercial activated earth) added and mixture stirred rapidly for five minutes. Cooled and filtered.

Sample 3,—ten cc. of 10 per cent hydrochloric acid were added and the mixture stirred rapidly for five minutes. After settling, the acid was removed and the clear oil washed with water until washings were neutral to litmus. Dried with anhydrous sodium sulphate and filtered.

Sample 4,—ten cc. of 10 per cent sodium hydroxide were added and the mixture stirred rapidly for five minutes. Allowed to settle and the clear oil

washed with water until washings were neutral to litmus. Dried with sodium sulphate and filtered.

Equal volumes of each sample were then placed in small uncorked bottles and kept in a dark cupboard. Oxygen uptakes were determined on them immediately after refining, one week later and one month later, comparison being made with a sample of the raw oil stored under the same conditions.

The results in figure 2 are those obtained on the samples kept for one week. They show definitely that refining had an effect on the inductive period of the oils. The refining experiments were not precise enough to establish which treatment rendered the oil most susceptible to oxidation. As in other experiments the oxygen-uptake curves for the refined oils were almost identical, but in all cases the inductive period was shorter than that of the raw oil. The writers have not been able to find any relation between the decolourizing efficiency of various refining processes and the reduction in inductive period.

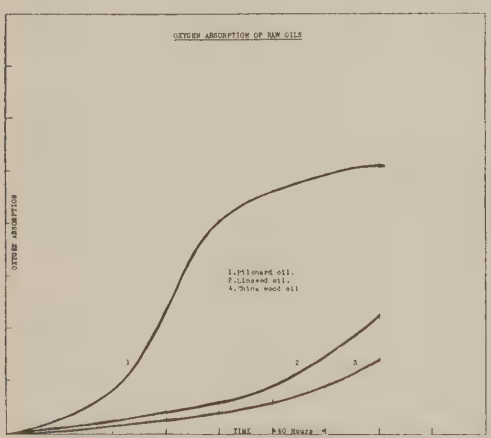

FIGURE 1

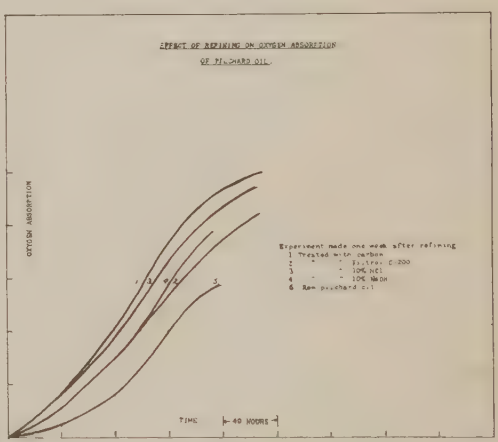

FIGURE 2

A further interesting observation was made in connection with these experiments. Immediately after refining, the oils showed an inductive period only slightly shorter than that of the unrefined sample. Figure 2 shows the results obtained after a period of one week. After one month the refined samples absorbed oxygen almost immediately upon placing in the oxygen-uptake apparatus. The raw sample, on the other hand, still exhibited a definite inductive period which, however, was shorter than that of the fresh raw oil. Apparently the refining treatments did not entirely remove the anti-oxygens originally present and as the samples slowly became oxidized during storage their susceptibility to further oxidation increased.

PREPARATION AND ACTION OF DRIERS

The influence of metallic and other catalysts on pilchard oil has been studied in detail both in regard to the effect on the rate of oxidation and the influence on drying and film properties. The information in the literature concerning the

effectiveness of driers in accelerating oxygen absorption pertains chiefly to linseed oil and the findings of various investigators quite frequently lack agreement, presumably because of variations in the oils used. Whilst it is true that all drying oils respond in much the same manner to the influence of driers, the effects often differ in magnitude. The driers used in the following experiments include most of the types used in industry together with some special ones. They include the so-called "soluble driers" consisting of the metallic soaps of the fatty acids from pilchard oil, linseed oil and China wood oil; resinates, oxides and certain organic and inorganic salts.

To compare the influence of various metals on the rate of oxidation of pilchard oil, driers were prepared by making soaps of pilchard oil fatty acids and various metals and then dissolving the soaps in pilchard oil. The metallic soaps were made by adding solutions of inorganic salts of the different metals to aqueous solutions of the potassium soaps of pilchard oil fatty acids. The soaps precipitated, some as hard horny masses, others in a more spongy form. The soaps were then dissolved in pilchard oil (about 65 gm. of moist soap in 270 gm. of pilchard oil) by heating in an inert atmosphere for two hours at 160° C. The behaviour of these soaps on heating, together with the metal content of the resulting solutions, are given in table I. These solutions were not necessarily saturated as the solution of the various soaps in the oils was retarded by the fact that the wet soaps were used. This procedure was followed because it was found that it was almost impossible to prepare the dried soaps without oxidation. Wherever necessary, the oil-soap solutions were diluted with pilchard oil so as to make the concentration 0.03 per cent (calculated as monoxide of the metal). This concentration was chosen because it was the limit of solubility in the case of some of the metals.

The soaps of cerium, nickel and the alkaline-earth metals gave the most frothing during the preparation of concentrated drier solutions, cobalt and manganese slightly less, and the remainder of those investigated gave little if any. Copper and iron soaps dissolve to some extent in the cold to give brilliant green and brick-red solutions respectively, but they are not very soluble. On heating, these solutions turn dark very readily.

The lead-containing pilchard oil solutions behave in an interesting manner. The lead compounds were by far the most soluble of all the driers examined. The hot solutions are clear although dark in colour; but on cooling, considerable quantities of solid lead soaps come out of solution. If these solids be removed and the clear solution be allowed to stand for some days, a further precipitate develops until a sort of equilibrium is reached. At this point no further precipitation occurs unless the solids are removed. By removing the solids when the equilibrium is reached, several successive precipitations can be obtained.

An examination of the purified precipitate showed it to be a somewhat crystalline white powder containing 40 per cent lead combined with solid fatty acids of m.p. 50.5° C., iodine value 1.2 and mean molecular weight of 254 (by titration). The precipitate, therefore, probably is the lead salt of the solid fatty acids of the pilchard oil originally saponified. There is some evidence, however,

TABLE I.—Some properties of pilchard oil soaps used as driers

Metal	Colour and texture of pilchard oil soap	Behaviour of soap during dissolution in pilchard oil	Metal content of oil solutions (as oxide) (per cent)
Cobalt	Purple-grey; fine and granular.	Considerable foaming during expulsion of water.	0.08
Manganese	Grey-green; granular but soft.	do.	....
Lead	Sticky and stringy mass. Deep buff.	Extensive foaming during expulsion of water.	8.80
Cerium	Buff. Similar to lead.	Extreme foaming.	0.13
Uranium	Yellow; granular and soft.	No foaming.	0.14
Copper	Blue green; granular and soft.	No foaming.	0.05
Iron	Grey green; brown on oxidation; soft and sticky.	No foaming.	0.03
Nickel	Green; granular and sticky when warm.	Extensive foaming.	0.27
Zinc	Buff; granular and porous.	No foaming.	0.28
Chromium	Grey-blue; spongy and cheesy.	No foaming.	....
Cadmium	Buff; granular and porous.	Slight foaming.	....
Aluminum	Buff; granular and spongy.	Slight foaming.	0.17
Magnesium	Buff; waxy.	Extensive foaming for short period.	0.06
Barium	Buff; granular and porous.	Considerable foaming.	0.04
Calcium	Soft and cheesy; buff.	Extreme foaming.	0.11
Strontium	Buff; soft and pasty.	Extreme foaming.	0.03
Mercury	Buff; waxy, granular.	No foaming.	0.06

that such precipitation may be caused by the action of the driers on pilchard oil because similar precipitates are formed when lead oxide is heated in neutral pilchard oil or when the lead salts of linseed oil fatty acids are dissolved in pilchard oil in the cold. In these cases the formation of the precipitate is slower but still extensive. Many other metals have the same tendency to precipitate, but to a much smaller extent. When drier solutions are diluted with pilchard oil to concentrations used in paint and varnish work the precipitation is observable only in the case of lead.

Various metallic salts of the fatty acids of linseed oil, China wood oil and of resin were also prepared and examined. The "linoleates" (from linseed oil) are in general more soluble than the metallic salts of pilchard oil fatty acids; on the other hand the "tungates" (from tung oil) are less soluble. Both lead linoleate and lead tungate, when dissolved in pilchard oil, even in as low a concentration

as 1 per cent. will in time yield precipitates of solid lead soaps. Precipitation occurs more rapidly with tungates.

Numerous metallic oxides and salts were also incorporated in pilchard oil by heating in an inert atmosphere. The solubility of cobalt oxide was slightly greater than that of the acetate or borate, but the last two gave paler solutions. They showed only a slight tendency to precipitate solid soaps from concentrated solution in pilchard oil. On the other hand, manganese dioxide, acetate and borate gave dark solutions which on standing gave considerable precipitates of solid soaps.

As might be expected, compounds of vanadium, bismuth, antimony and tin behaved somewhat differently on being heated in pilchard oil. As a rule they were converted into their oxides and dispersed through the oil in a colloidal form. On standing, the larger particles settled out, but a considerable proportion remained in suspension even after standing for one year. All these solutions were opaque and quite dark.

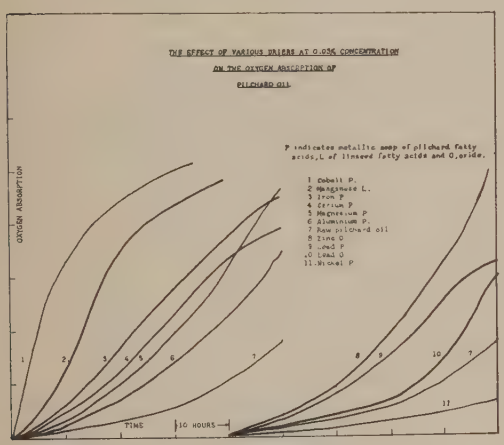

FIGURE 3

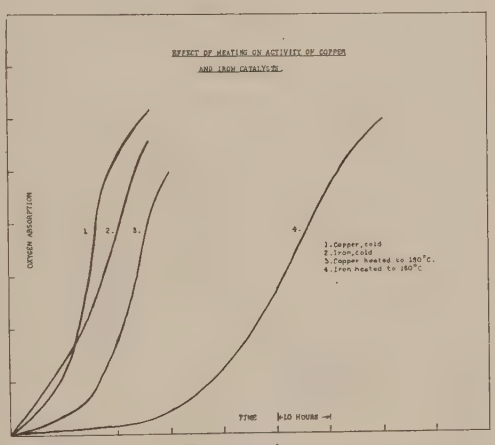

FIGURE 4

Relatively few driers exhibited any outstanding effect on the oxidation of pilchard oil. The most active were cobalt and manganese followed by copper, iron, cerium, aluminium and lead. The relative effects of a selected group are shown in figure 3. As pointed out before, slight differences in the mode of preparation of the driers or the manner of their incorporation in pilchard oil affects their activity. Cobalt and manganese are much superior to all others regardless of the manner of preparation. The activity of the other driers may not always follow the exact order given in the figure, but their average activity is fairly well indicated.

The state of the driers, *i.e.*, whether they are in true or colloidal solution, considerably influences their activity. This is shown very well by the activity of copper and iron soaps. As stated before, these go into solution in the cold to give brightly coloured solutions which darken when heated. In figure 4 is shown the activity of the cold and heated solutions. The latter, consisting of a colloidally dispersed system, is less active.

Since cobalt and manganese are so much superior in catalytic activity, test runs were made in order to ascertain the optimal concentration and temperature of incorporation. It was found that solution at 125° C. gave slightly better results than at higher temperatures. Various concentrations were then tested, incorporating the catalyst at a temperature of 125° C. for three hours under carbon dioxide. The results showed that the maximal effect is given with the equivalent of approximately 0.05 per cent cobalt oxide and from 0.15 to 0.20 per cent of manganous oxide.

INFLUENCE OF PIGMENTS AND INERT MATERIAL

It is well known that some pigments used in paint manufacture have an effect on the rate of oxidation of the oil vehicle. In some cases this is due to adsorption of the drier by the pigment, thus retarding oxidation, whilst in others

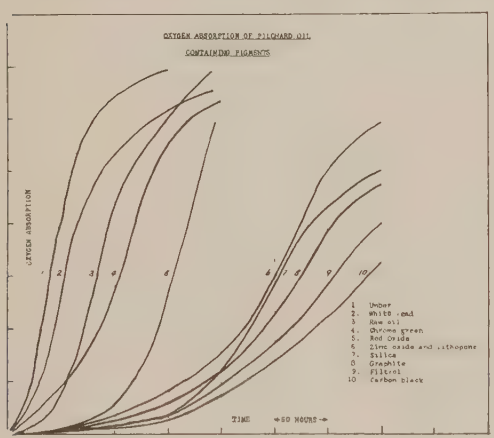

FIGURE 5

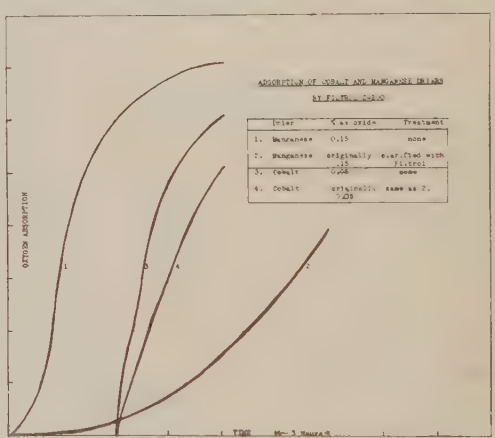

FIGURE 6

the pigment itself may act as a drier and thus accelerate oxidation. This tendency has been investigated in the present work by thoroughly grinding 10 grams of the pigment in 100 grams of raw pilchard oil, heating the mixture for 15 minutes at 160° C., cooling and determining the oxygen absorption in the usual manner. Representative data plotted in figure 5 show that umber and white lead, containing manganese and lead respectively, have an accelerating action, a fact well known in paint technology. The green and yellow "chrome" pigments had but little effect but zinc oxide and the inert materials such as graphite, silica, Filtrol and carbon black had a definite retarding effect. The last four materials have a high adsorptive capacity and their retarding effect is most likely due to the adsorption of free fatty acids and peroxides which, when free, catalyze oxidation. In general, these results are similar to those obtained with linseed oil.

The catalytic effect of driers and pigments can be followed with fair accuracy only while the oil remains liquid. When drying occurs and a surface skin forms, the diffusion of oxygen into the oil is impeded and the effect of catalysts obscured.

This is particularly true of pilchard oil which oxidizes even more rapidly than linseed oil. In the present experiments the amount of pigment was purposely reduced so that this effect was minimized. The curves given are fairly indicative of the action of the pigments on the initial oxidation of the oil.

Further evidence regarding the adsorptive effect of inert materials was obtained by treating pilchard oil, containing cobalt and manganese driers, with Filtrol. If the linoleates of these metals are dissolved in pilchard oil, little if any of the metallic soap is removed by the Filtrol. On the other hand, if small amounts of the oxides of these metals are heated with pilchard oil, they become colloidally dispersed to give clear solutions but treatment with Filtrol almost completely removes the metallic compounds. The effect of the Filtrol treatment is shown in figure 6. Thus the rate of oxygen uptake of the solution containing cobalt linoleate was only slightly affected, while the uptake in the case of the manganese oxide solution was greatly reduced after Filtrol treatment.

MISCELLANEOUS TREATMENTS

The effects of various other treatments on the oxygen absorption of pilchard oil have been investigated. Samples of oil polymerized by heat in an inert atmosphere showed an increase in inductive period proportional to the time and temperature of polymerization. The rate of oxidation at the end of the inductive period is also retarded and the total amount of oxygen absorbed is reduced. Samples thickened by ultraviolet light in an inert atmosphere, however, showed a decrease in inductive period, while the total oxygen absorption seemed to be diminished.

As with other drying oils, pilchard oil, when blown with air, yields a product which shows no inductive period and which oxidizes rapidly. The total oxygen absorption, however, is reduced.

The effect of sulphur dioxide treatment on the oxidation of pilchard oil is of interest. This treatment, which has been described before (Brocklesby and Denstedt 1933), entirely eliminates the inductive period of the raw oil but has no appreciable effect on the subsequent rate of oxidation. It would appear that the sulphur dioxide destroys the anti-oxygens present in the oil but from a consideration of the film properties of the treated oils it is apparent that the fatty acids themselves are in some way affected. This reaction is being studied further.

Anti-oxidants such as hydroquinone, pyrogallol and maleic acid have a marked retarding effect on the rate of oxidation of pilchard oil. Because of the readiness with which the highly unsaturated fatty acids of the oil are oxidized, however, the above anti-oxidants have to be used in greater concentrations than is necessary for less highly unsaturated oils.

ACKNOWLEDGMENT

The writers gratefully acknowledge the laboratory assistance of Mr. P. A. Sunderland throughout this investigation.

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The Secretion of Urea and Chloride by the Elasmobranch Stomach

By F. C. MacIntosh
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(*Received for publication July 18, 1935*)

ABSTRACT

The finding of Babkin, Chaisson and Friedman that destruction of the spinal cord in the skate leads to a continuous secretion of gastric juice is confirmed. During the course of this secretion the chloride content of the gastric juice rises or remains unchanged, while the urea content gradually falls from a value of over 1 per cent to 0.1 per cent or less. There is no corresponding change in the urea or chloride content of the blood.

INTRODUCTION

The mechanism of gastric secretion in elasmobranchs has received comparatively little attention. It is known that the mucosa of the resting stomach is strongly acid in reaction, and that a secretion of acid gastric juice occurs in response to the ingestion of food. Nevertheless the usual experimental procedures for obtaining gastric juice in higher vertebrates, such as stimulation of the vagus or splanchnic nerves or the administration of autonomic drugs or histamine, evoke no secretion from the elasmobranch stomach (Babkin, Chaisson and Friedman 1935; Dobreff 1927). Babkin, Chaisson and Friedman (1935), however, working on skates whose spinal cords had been destroyed, were able to demonstrate a continuous secretion of acid gastric juice, beginning one to three days after the operation and lasting as long as two weeks. They consider this secretion due probably to a loss of tonus of the splanchnic blood vessels following removal of the influence of the sympathetic nervous system. When such experiments were prolonged over a period of a week or more, a gradual decrease was noted in the osmotic pressure of the secretion and the blood: they suggested that this was due to the loss of some unknown constituent from the blood to the secretion. The Cl concentration of both the blood and the gastric juice remained more or less constant.

The present work was an attempt to extend the data obtained by Babkin, Chaisson and Friedman, with especial reference to the changes in the chloride and urea content of the blood and gastric juice during the course of the paralytic secretion. It is well known that urea occurs in very high concentration (over 2 per cent) in the blood of elasmobranchs, and Babkin and Komarov (1931) have shown that it occurs also in their gastric juice in concentrations of about 1 per cent. It was thus to be expected that the changes noted in the osmotic

pressure of the blood and secretion might be due to a reduction in the urea content of these fluids.

METHODS

The animals used, *Raja diaphanes* and *R. erinacea*, were prepared as described by Babkin and his co-workers, by pithing the spinal canal as far as the tail region. They were kept in shallow tanks of flowing sea-water. Gastric juice was obtained daily by gentle aspiration through a narrow glass tube passed through the oesophagus, the mouth and pharynx being first swabbed with cotton wool to minimize the danger of contamination with sea-water; in the absence of any fluid in the stomach, the reaction of the gastric mucosa was tested by passing through the glass tube a blunt wire carrying litmus and congo red papers. The animals remained in good condition for a week or more, the longest period of survival being about 18 days. At the end of an experiment blood for analysis was withdrawn from the ventral aorta and sodium oxalate added to delay (but not prevent) coagulation. Blood urea was determined on the Folin-Wu (1919) protein-free filtrate by the method of Van Slyke and Cullen (1914); blood chlorides by the open Carius method of Wilson and Ball (1928); urea and chloride determinations on the filtered gastric juice by the methods of Van Slyke and Cullen and of Harvey (1910) respectively. Ammonia blanks in the urea determinations were found to be negligible except when the blood or gastric juice had stood for some time at room temperature, suggesting the production of ammonia from urea: they were therefore omitted in most of the analyses.

RESULTS

As was noted by Babkin and his co-workers, the gastric mucosa of fasting skates reacts strongly acid to litmus and congo red. No fluid other than a little mucus could be obtained from the stomachs of fasting skates whose spinal cords were intact, except in one or two instances in which a little slightly alkaline fluid, apparently sea-water swallowed during the act of passing the tube, was withdrawn; in these cases the mucosa itself was distinctly acid.

After destruction of the spinal cord, it was possible in the majority of animals to obtain fluid from the stomach in quantities of 0.5 to 15 cc. per day. This fluid was usually strongly acid to litmus and congo red and was either clear or mixed with a little mucus. Analyses were made daily on groups of three or more animals pithed simultaneously, the gastric contents from all being tested for acidity, combined, and filtered. In some cases, especially shortly after pithing, large quantities of a neutral or alkaline fluid, resembling sea-water in Cl content, was withdrawn; this was nearly always associated with a marked reduction in the tonus of the oesophagus, so that the catheter passed very freely into the stomach. In these animals the gastric juice was presumably contaminated with sea-water which had been swallowed or had entered passively. All samples of gastric contents which were not strongly acid to congo red, or which contained food rests, were discarded. The daily volume of the gastric

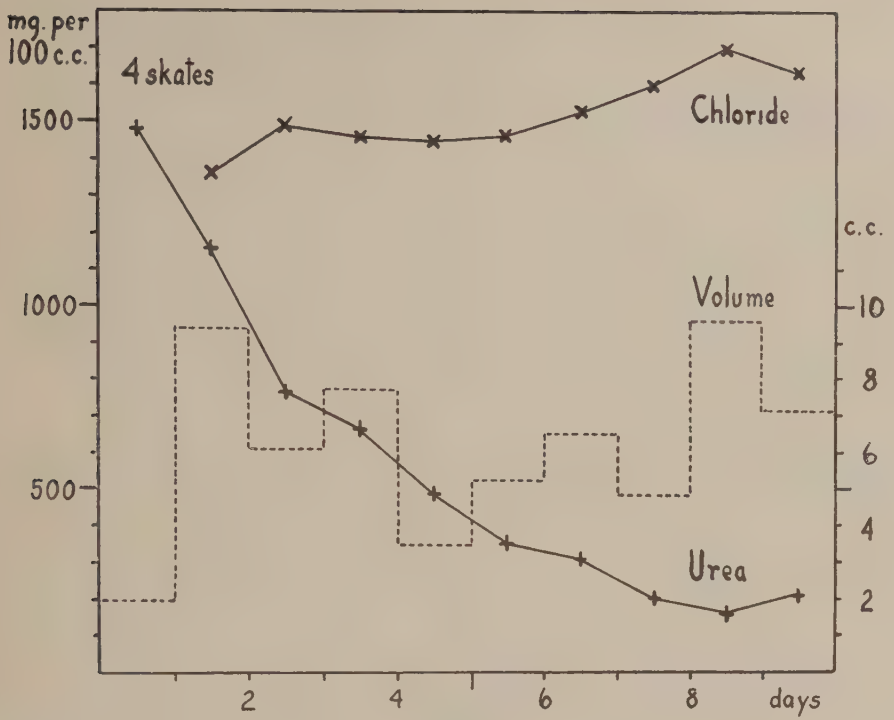

FIGURE 1

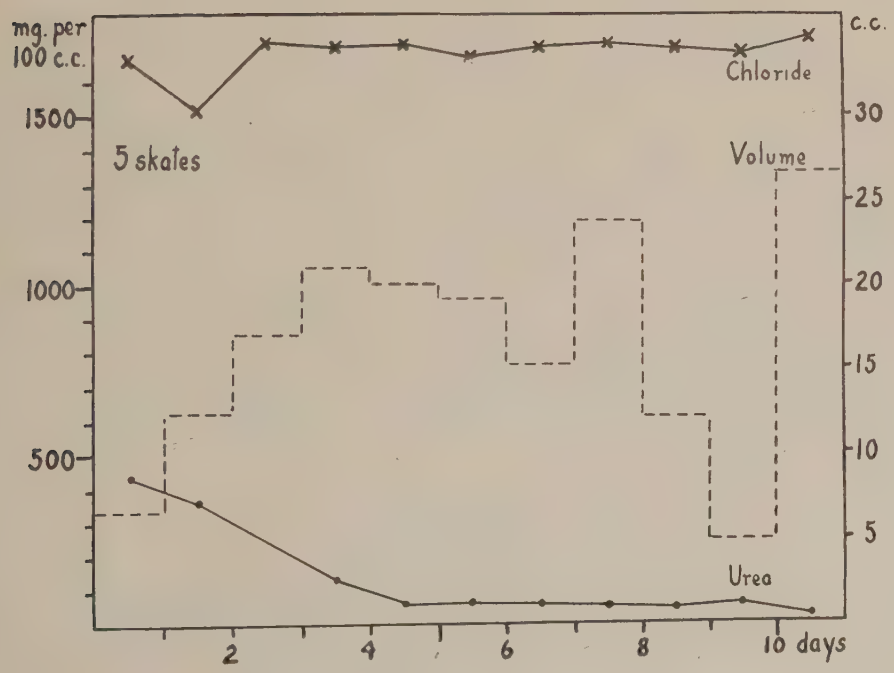

FIGURE 2

secretion varied considerably, either from an actual change in the rate of secretion or by loss of some of the juice by passage into the intestine.

The chloride content of the gastric juice tended to rise somewhat from day to day, especially in the first few days after pithing, but always remained distinctly less than that of sea-water (1.84 per cent). The most striking change, however, was in the urea concentration, which fell off gradually from a high figure to very low levels. The results of two series of experiments are recorded graphically in figures 1 and 2. No quantitative determinations of acidity were made, but the pH as judged by the reaction to Töpfer's reagent appeared to decrease (acidity increased) as the experiment progressed. Calculation of the osmotic pressure of the secretion, assuming this to depend entirely on the urea and chloride present, gives values from 8 to 16 per cent less than that of sea-water, with considerable fluctuation from day to day.

In contrast to what was expected, analyses of blood urea and chlorides gave very similar values for all animals, no matter under what conditions they had been kept. The values obtained are summarized in the table.

No. of skates	Condition	Cl gm. %		Urea gm. %	
		Limits	Avg.	Limits	Avg.
4	Freshly caught	0.849-0.902	0.870	2.12-2.17	2.15
4	Starved 4-7 days	0.843-0.880	0.859	2.13-2.23	2.19
3	Pithed 3 days	0.866-0.880	0.873	2.12-2.18	2.15
5	Pithed 12 days	0.820-0.936	0.895	2.11-2.33	2.19
4	Pithed 14 days	0.887-0.936	0.908	2.10-2.14	2.12

No significance can be attached to the slightly higher values for Cl obtained in animals which had been pithed for 12 days or more, since the figures in each group vary over a considerable range. The results are hard to reconcile with those of Chaisson (1933) and of Chaisson and Friedman (1935) who find that destruction of the spinal cord lowers the osmotic pressure of the blood. It is to be pointed out, however, that their osmotic pressure determinations were made on serum, while the analyses of the present work were made on whole blood. Dodds and Smith (1923) have shown that during gastric secretion in man the Cl content of the blood plasma falls while that of the corpuscles rises, and it is possible that a similar mechanism exists in elasmobranchs. Furthermore, only 90 per cent or less of the osmotic pressure of the blood as given by Chaisson and Friedman can be accounted for by its chloride and urea content; the fall of the blood Δ may therefore be due to a depletion of some other constituent.

DISCUSSION

The significance of the "paralytic" secretion of gastric juice in the skate has been discussed by Babkin, Chaisson and Friedman. Their results are fully confirmed in the present work and no observations have been made which conflict with their interpretation.

The reason for the gradual decline in the urea content of the gastric juice is not at present clear. The amount of urea lost in the secretion would be insufficient to cause any great fall in the blood urea level: thus over a period of 10 days the total urea excreted in the gastric juice of 4 skates was only 0.324 gm. Since urea occurs in high concentration in the tissues (Smith 1929) as well as in the blood, this would mean a lowering of the urea content of the animal of only a few mg. per cent, an effect which would be undetectable. It is possible, however, that the stomach may have a kidney-like action, and excrete only what urea is produced above that required to keep the blood urea level constant. In any case it would seem probable, since the urea content of the gastric juice varies so greatly, independently of the blood urea, that this substance occurs in the gastric juice by a true process of secretion, and not merely by transudation from the blood stream.

My thanks are due to Dr. B. P. Babkin, who suggested this work, for his helpful advice and criticism. I am also much indebted to the Biological Board of Canada for granting me the facilities of the Atlantic Biological Station, St. Andrews, N.B., and to Dr. A. H. Leim and the staff of the Station for much valuable assistance.

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Hydroids from the Queen Charlotte Islands

By C. McLean Fraser
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(*Received for publication November 25, 1935*)

ABSTRACT

Tubularia aurea, *Ophiodes corrugata* and *Selaginopsis trilateralis* are described as new. The gonangium of *Thuiaria distans* is described. *Tubiclava cornucopiae*, *Turris neglecta*, *Perigonimus serpens*, *Campanularia gigantea* and *Clytia minuta* are now first reported from the Pacific.

On the invitation of Dr. W. A. Clemens, through the courtesy of the Canadian Hydrographic Service, as represented by the Commanding Officer on the coast of British Columbia, Mr. H. D. Parizeau, June and July, 1935, was spent with the Survey Ship, *Wm. J. Stewart*, making marine zoological collections, along the coast of the Queen Charlotte islands. During August and the first part of September, under Mr. Parizeau's direction, other collections were made and forwarded for examination.

Although this collecting was somewhat limited in scope, the fact that these shores have been biologically untouched, makes the distribution records particularly interesting.

Most of the collecting was done on the west coast, where the contour is very rugged, especially in the vicinity of Tasoo harbour. The slope down to the shore and on into the sea-bottom is so precipitous that there is no evidence of any continental shelf. The inlets are in the nature of fiords, deep, with muddy bottom, but usually with a definite threshold. Hence, except near the entrance, they are not biologically promising. On the rocks near the mouth of the inlets, exposed at low spring tides, life is very abundant, but the number of species is not very great.

In and around Houston Stewart channel and Skidegate channel, where, in places, the water is shallow and the currents strong, there is much variety and an abundance of individual organisms.

There are comparatively few intertidal species of hydroids and as the dredging was not extensive, it cannot be expected that a very large proportion of the hydroid species was obtained. It was an agreeable surprise to find, on examination of the material collected, that 96 species were represented. Of these 96, three, *Tubularia aurea*, *Ophiodes corrugata* and *Selaginopsis trilateralis*, are de-

scribed as new, the gonangium of a fourth, *Thuiaria distans*, has not been reported previously, and five others, *Tubiclava cornucopiae*, *Turris neglecta*, *Perigonimus serpens*, *Campanularia gigantea* and *Clytia minuta*, are new to the Pacific. These nine species are considered in this paper.

Tubularia aurea new species (Figure 1)

Trophosome. Individual zooids growing from a slightly annulated stolon to a height of 3 cm. The pedicel has a heavy perisarc, almost to the distal end, without annulations. Hydranths with about 20 proximal and 30 distal tentacles.

Gonosome. Gonophores large, in loose racemes, with few to each cluster. The terminal processes are quite large.

Colour. Stolon and pedicels, a rich, golden yellow; hydranth white.

Distribution. Danger rocks, at the east end of Houston Stewart channel, low tide; Flamingo harbour, on gastropod shells, attached to *Macrocystis*.

Ophiodes corrugata new species (Figure 2A, 2B)

Trophosome. Individual zooids, or small colonies, growing from a much annulated stolon. The individual zooids have short pedicels, sometimes less than 0.3. mm., but no matter how short they are, they have at least one or two corrugations or annulations. When a colony appears, the stem is annulated like the stolon, but the diameter is much less. The individuals in the colony are irregularly arranged, and each one looks like the individual zooid attached to the stolon. The terminal portion gradually increases in diameter to a prominent flare.

The tentacular organs are relatively large, sparsely scattered over the stolon, and over the stems of the colonies; none was observed directly on the hydrophore pedicels. They are tubular, but flare slightly at the distal margin.

Gonosome. Not observed.

Distribution. Off Rose harbour in Houston Stewart channel, 30 f. (55 m.).

Selaginopsis trilateralis new species (Figure 3)

Trophosome. A rigid colony, 18 mm. high, is regularly, pinnately branched, the branches constricted proximally; hydrothecae in two series on the greater portion of the stem but in three distinct series on the branches; hydrothecae about one-fourth free; margin with two, low, rounded teeth; operculum of two flaps.

Gonosome. Not observed.

Distribution. In Houston Stewart channel, near Rose Harbour, 30 f. (55 m.), and in the western portion of the channel, 15-18 f. (25-30 m.).

Thuiaria distans Fraser (Figure 4)

Thuiaria distans Fraser. Vancouver Is. Hydroids, 1914, p. 197.

Thuiaria geniculata Fraser. Monobrachium parasitum and other west coast Hyd., 1918, p. 136.

Trophosome. Stem erect, geniculate; branching regularly alternate; branches, long, slender, geniculate, either unbranched or dichotomously branched, usually three hydrothecae on the stem between two successive branches on the same side; on the branches, the hydrothecae are alternate, very distant for this genus, each hydrotheca placed at a bend in the branch; when the branch is dichotomously branched, there is a hydrotheca in the angle; hydrotheca, largest in the centre, tapering both ways, curved to turn well outward, with the margin vertical, about one-half free; margin without distinct teeth, but rather bilateral; operculum of one abcauline flap.

Gonosome. (Not previously observed). Gonangia small, elongated, obovate, growing, almost sessile, from the stem and distal branches, the attachment being just below the base of the hydrothecae; opening terminal, with no definite collar.

Distribution. 9½ miles south of Marble island, 190 f. (350 m.).

Note.—In 1877, Allman described a species which he named *Thuiaria distans* (Hyd. of Gulf Stream, 1877, p. 27), but as pointed out by Hartlaub (Revision Sertularella-Arten, 1900, p. 100), this species should be placed in the genus *Sertularella*. Consequently, the name stands for this species.

Tubiclava cornucopiae Norman

Tubiclava cornucopiae Norman, Ann. and Mag. N.H. (3) xiii, 1864, p. 62.
Merona cornucopiae Norman, Ibid., (3) xv, 1865, p. 9.
Tubiclava cornucopiae Hincks, Br. Hyd. Zooph., 1868, p. 11.

Distribution. Outside Masset inlet, 15 f. (27 m.).

(?) **Turris neglecta** Lesson

Turris neglecta Lesson, Hist. Nat. Zooph. 1843, p. 284.
Allman, Ann. and Mag. N.H., (3) xiii, 1864, p. 352.
Hincks, Br. Hyd. Zooph., 1868, p. 13.

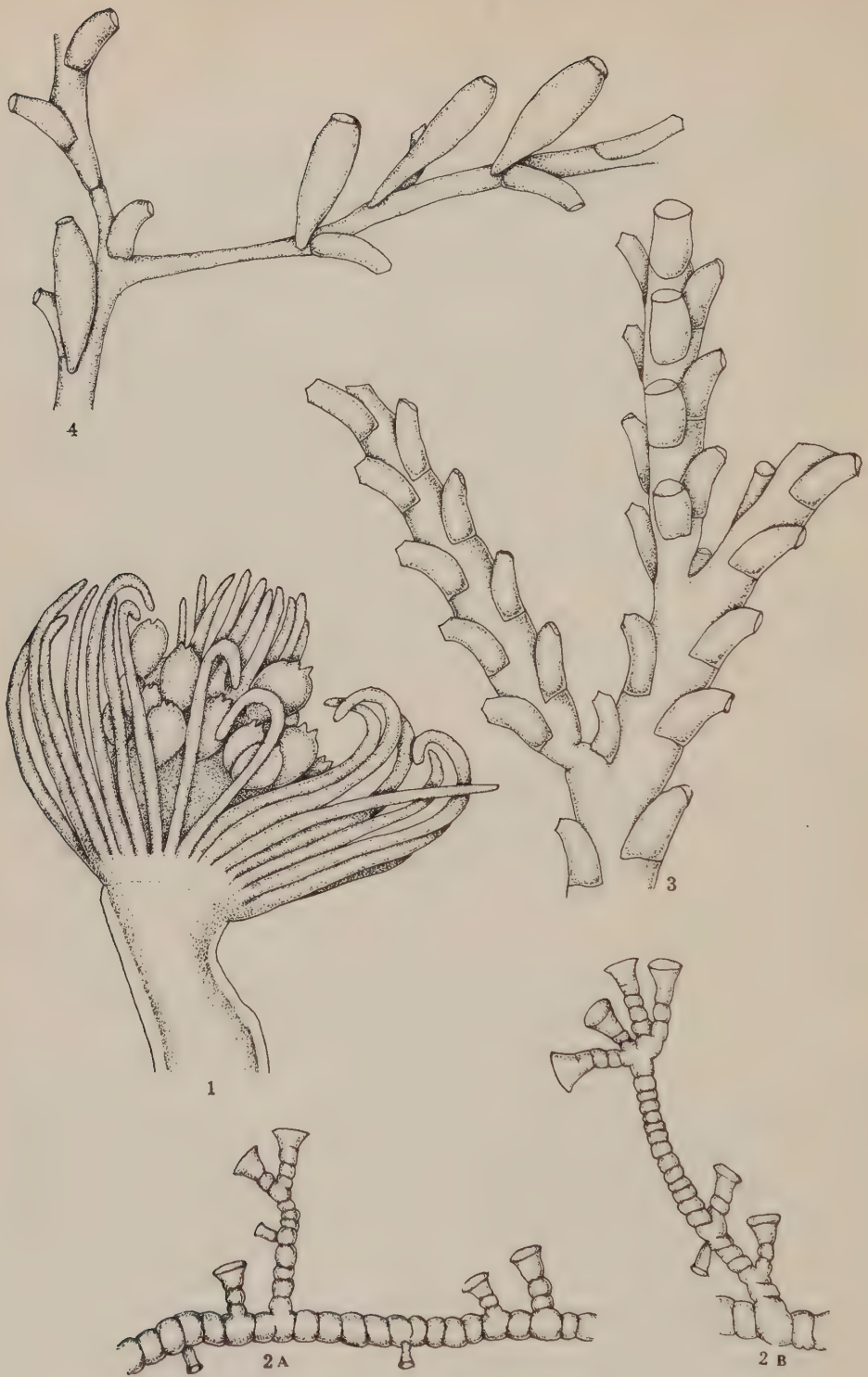
Distribution. North shore of Hibben island, as it faces Inskip channel, on the carapace of a crab, *Pugettia gracilis*, low tide.

Note.—These specimens seem to answer perfectly to the description and figures of this species. As the medusa *Turris neglecta* has not been reported from the northern Pacific, it is possible that it may be the hydroid of some other species of the family to which *Turris neglecta* belongs. On the other hand, it is quite possible that the medusa is present in the Pacific even if it has not been reported.

Perigonimus serpens Allman

Perigonimus serpens Allman, Ann. and Mag. N.H., (3) xi, 1863, p. 10.
Hincks, British Hyd. Zooph., 1868, p. 95.

Distribution. In Rennell sound, between Gospel island and the south shore, 60-70 f. (110-130 m.); near the north shore of Tasoo harbour, 7-14 f. (10-25 m.); west of Rose Spit, 16 f. (30 m.).



EXPLANATION OF FIGURES

Drawings by Clara A. Fraser. Magnification—20 diameters

1. *Tubularia aurea.* One hydranth showing tentacles and gonophores. 2. *Ophiodes corrugata.* A and B. Showing stolon, individual zooids and colonies. 3. *Selaginopsis trilateralis.* Portion of colony to show hydrotheca arrangement. 4. *Thuiaria distans.* Portion of colony to show gonangia.

? **Campanularia gigantea** Hincks

Campanularia gigantea Hincks, Ann. and Mag. N.H., (3) xviii, 1866, p. 297.
Hincks, Br. Hyd. Zooph., 1868, p. 174.

Distribution. 9½ miles south of Marble island (53°03′ N. Lat., 132°40′ W. Long.). 190 f. (350 m.).

Clytia minuta (Nutting)

Campanularia minuta Nutting, Hyd. Woods Hole Region, 1901, p. 345.
Clytia minuta Fraser, New England Hyd., 1912, p. 44.

Distribution. In large tow-net, near surface, against the ebb-tide, in the western portion of Houston Stewart channel.

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